

## **Programmable Thermostats for MPLM Shell Heater Control ULF1.1 Thermal Performances**

### **ABSTRACT**

The Multi-Purpose Logistics Module (MPLM) is the primary carrier for "pressurized" logistics to and from the International Space Station (ISS). The MPLM is transported in the payload bay of the Space Shuttle and is docked to the ISS for unloading, and reloading, of contents within the ISS shirt sleeve environment. Foil heaters, controlled originally with bi-metallic thermostats, are distributed across the outside of the MPLM structure and are utilized to provide energy to the structure to avoid exposure to cold temperatures and prevent condensation.

The existing bi-metallic, fixed temperature set point thermostats have been replaced with Programmable Thermostats Modules (PTMs) in the Passive Thermal Control Subsystem (PTCS) 28Vdc shell heater circuits. The goal of using the PTM thermostat is to improve operational efficiency of the MPLM on-orbit shell heaters by providing better shell temperature control via feedback control capability. Each heater circuit contains a programmable thermostat connected to an external temperature sensor, a Resistive Temperature Device (RTD), which is used to provide continuous temperature monitoring capability. Each thermostat has programmable temperature set points and control spans. The data acquisition system uses a standard RS-485 serial interface communications cable to provide digital control capability.

The PTM system was designed by MSFC, relying upon ALTEC support for their integration within the MPLM system design, while KSC performed the installation and ground checkout testing of the thermostat and RS-485 communication cable on the MPLM FM1 flight module. The PTMs were used for the first time during the STS-121/ULF1.1 mission.

This paper will describe the design, development and verification of the PTM system, as well as the PTM flight performance and comparisons with SINDA thermal model predictions.

# **Programmable Thermostats for MPLM Shell Heater Control - ULF1.1 Thermal Performances**

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# Outline

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- Background
- Hardware Development
- STS-121 Mission Operations
- Flight Performance



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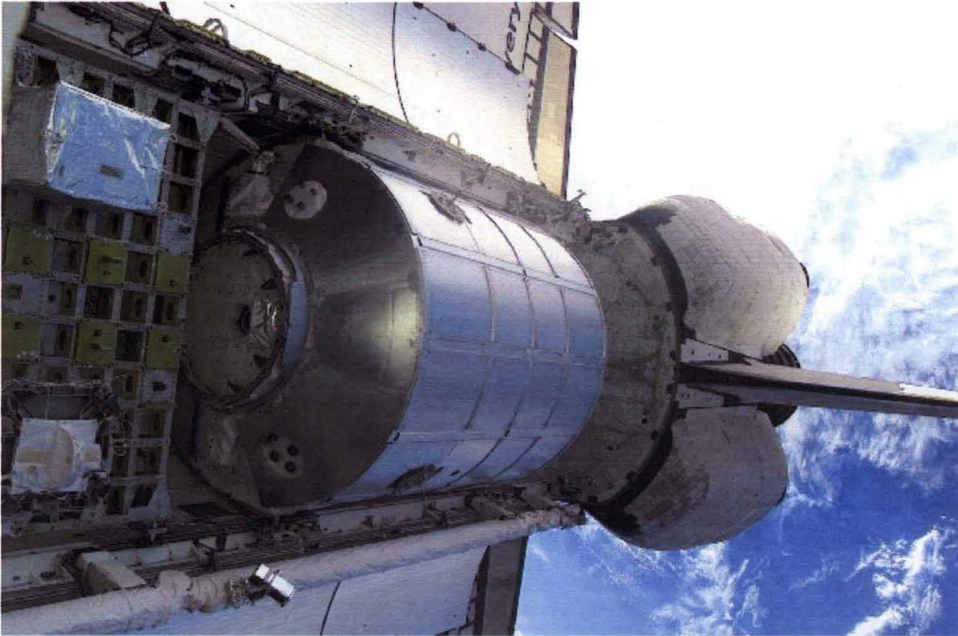
# Background



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# MPLM Description



- **Size:** 21' long X 15' diameter
- **Dry Weight:** 9800 lbm
- **Cargo Capacity:** 20000 lbm
- **Flight History:** 7 ISS missions

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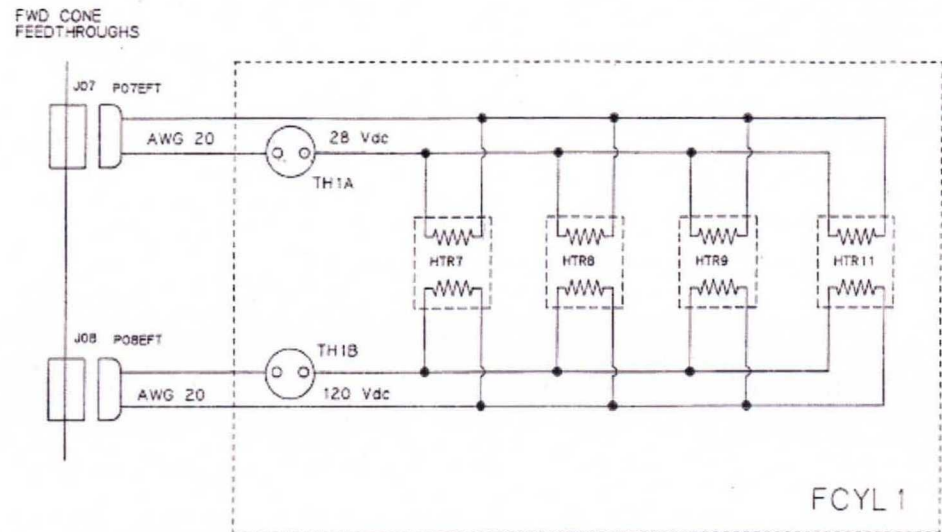
**MULTI-PURPOSE LOGISTICS MODULE (MPLM)** - The MPLM is a pressurized module used to transport cargo to/from the International Space Station (ISS). The Italian Space Agency (ASI)-built MPLM serves as the ISS "moving van", carrying laboratory racks filled with equipment, experiments, and supplies. The MPLM is transported in the Space Shuttle cargo bay and then docked to the ISS for cargo transfer. It can transport up to 16 racks with a maximum payload weight of 20,000 lbs (9,072 kg) in a controlled (human-rated) operating environment.

**ALTEC** (the Italian Space Agency MPLM sustaining engineering partner) and the Marshall Space Flight Center are responsible for the sustaining engineering activities associated with the MPLM, including support to Cargo Element Integration for each flight and real-time mission support.



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# MPLM Shell Heater System



## MPLM Shell Heater System:

- 2 separate circuits: 28V (STS mode) & 120V (ISS mode)
- 22 fused branches / 66 Kapton strip heater pads

## Forward Cylinder Electrical Schematic

## Purpose:

- Moisture/condensation prevention
- Cargo temperature conditioning (50-90F)
- Regulate internal pressure (13.9 -15.2 psi)



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# Issues w/ Bi-Metallic Thermostats

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- **Setpoints were set too high (81 to 95°F) for nominal mission timeline heater operations**
  - ⌘ Positive Pressure Relief Assembly (PPRAs) actuation would occur at these temperatures
  - ⌘ PPRA actuation exposes a risk of a valve not reseating and resultant venting of the MPLM environment
  - ⌘ Loss of MPLM environment prevents ingress/cargo transfer and loss of mission
  
- **Operational workarounds required for heaters ops w/ bi-metallic thermostats**
  - ⌘ Heaters manually cycled by crew from aft flight deck switch panel
  - ⌘ Mission-dependent profile required for shell heater ops
    - Preflight analyses define approx. heater cycle times and generate trend data
    - Real-time telemetry required to “fine-tune” and optimize heater operations
    - Real-time MOD support to coordinate crew activity
  
- **Unnecessary usage of Orbiter cryogenic resources (for power generation)**



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# Project Authorization

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ISS Program Office formally approved CR3578 in October 2000 for developing solid-state Programmable Thermostats to replace the 28V bi-metallic units

## Operational Goals:

- Provide temperature control w/ closed loop feedback
- Reduce mission operational impacts & crew interaction
- Improve Shuttle cryogenic fuel cell efficiency



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# **Hardware Development**



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# Project Deliverables

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- 100 Programmable Thermostat Modules (PTMs)
- 6 Data Recorder Modules (DRMs)
- GSE Laptop computer & Thermoview software
- RS-485 Serial Communications Cable
- PTM Installation & Cable Layout Drawings



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# Roles & Responsibilities

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- PTM & DRM designed, manufactured, and certified by MSFC
- GSE software designed and certified by MSFC
- RS-485 communications flight cable designed, manufactured, and certified by Boeing
- Hardware installation, cable routing layout, and MPLM electrical power harness wiring drawings provided by ALTEC
- Installation/ system checkout testing performed by Boeing and ALTEC

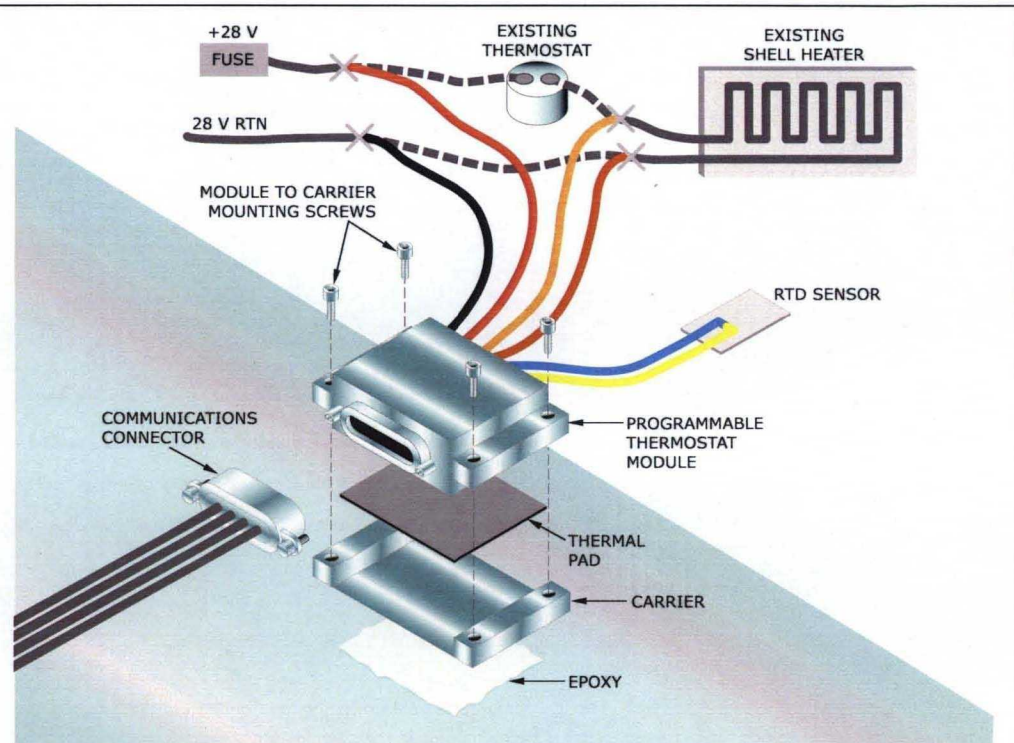


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# Programmable Thermostat

## Design Features:

- Size: 2.25" x 1.75" x 0.5"
- Weight: < 75 gm (w/o carrier); < 100 gm (w/carrier)
- C&DH: RS-485 serial communication protocol
- Software: Graphical Users Interface (GUI) developed for programming and monitoring
- Input Power: +9 to +28 VDC.
- External RTD temperature sensor
- External Heater : Up to 5A at +28VDC
- Programmable temperature set points and span. Setpoint/ span resolution: 0.1 °C
- Data Recorder Module (DRM) available in the same housing for recording status and temperature data for up to 32 PTM units connected on a single RS-485 bus.



MPLM PROGRAMMABLE THERMOSTAT HARDWARE



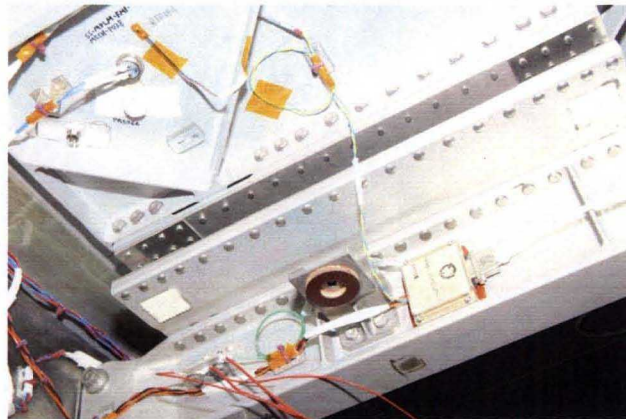
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# Flight Certification Process

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- Environmental Qualification/Acceptance testing conducted per SSP-41172 ISS test guidelines
- Thermostat hardware certified for 25 missions
- Extensive prototype development testing performed (1 PTM & DRM)
  - Thermal Cycling/Random Vibration/EMI/EMC
  - Adhesive bond strength (RTV bonding process validation)
  - Radiation susceptibility (Radiation-hardened EEE parts waiver)
- Lot qualification (10 PTMs & 1DRM)
- Acceptance tests (90 PTMs & 5DRMs)
- No test failures!



PTM18A on MPLM FM1



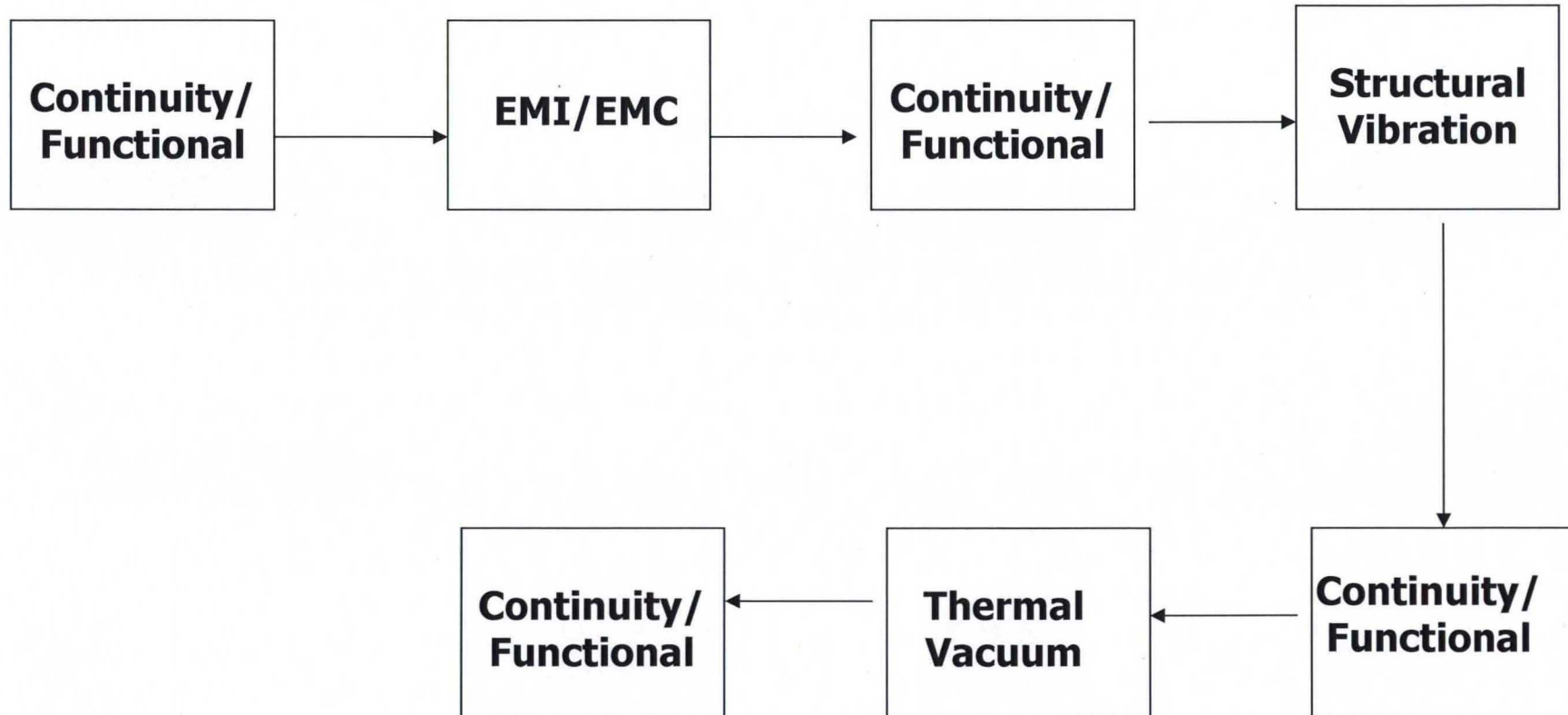
Qualification Test Fixture

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# Qualification Test Flow

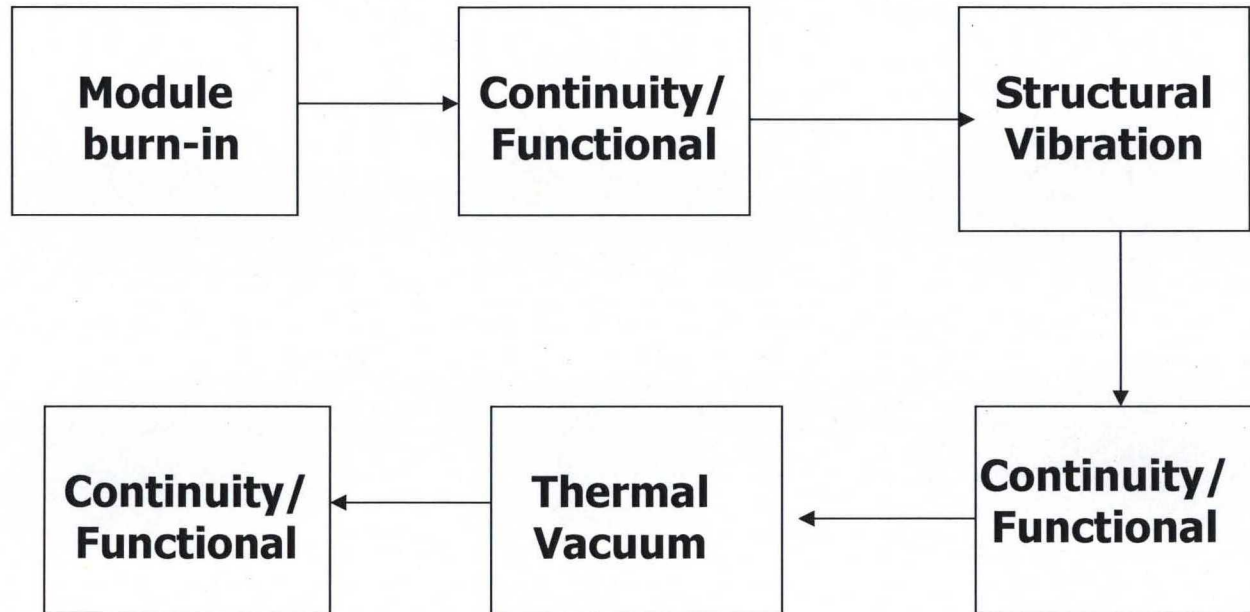
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# Acceptance Test Flow

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# Environmental Test Levels

## Random Vibration Levels

Frequency (Hz)	Qualification Level	Acceptance Level
20	0.04 g <sup>2</sup> /Hz	0.01g <sup>2</sup> /Hz
20 to 65	+7.6 dB/Octave	+7.6 dB/Octave
65 to 180	0.8 g <sup>2</sup> /Hz	0.2g <sup>2</sup> /Hz
180 to 360	-7.0 dB/Octave	-7.0 dB/Octave
360	0.16 g <sup>2</sup> /Hz	0.04 g <sup>2</sup> /Hz
360 to 1400	-2.6 dB/Octave	-2.6 dB/Octave
1400	0.05 g <sup>2</sup> /Hz	0.0125 g <sup>2</sup> /Hz
1400 to 2000	- 4.9 dB/Octave	-4.9 dB/Octave
2000	0.028 g <sup>2</sup> /Hz	0.007 g <sup>2</sup> /Hz
Composite	16.8 g <sub>rms</sub>	8.4 g <sub>rms</sub>

## Thermal Cycle Ranges

	Low Temperature	High Temperature	# of Cycles
Qualification	-24°F	+156°F	24
Acceptance	-4°F	+136°F	8



Qualification Duration = 810s in each of 3 mutually perpendicular axes.  
Acceptance Duration = 60s in each of 3 mutually perpendicular axes.

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# **STS-121 Mission Operations**



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# Mission Highlights

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- STS-121/ULF1.1 mission launched July 4, 2006
- 14 day mission duration
- 7<sup>th</sup> MPLM mission; 1<sup>st</sup> flight of new PTM system
- MPLM heater ops during downhill mission phase (FD10-13)
- MPLM daily pressure checks performed for monitoring
- 1<sup>st</sup> MPLM mission in which shell temperatures recorded during flight operations



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# Mission Phase Cabin Environment

Flight Phase	Cabin P Limits	Lower Limit Action Point	Requirement
Prior to Transfer to ISS (28V Heaters)	773.1 mmHg 14.95 psia	10 °C (50°F)	Accounts for MPLM spec, lower limit and PPRA
Transfer to ISS - includes vestibule outfitting (No Heaters)		(a) > 18.3°C (65°F) (b) > 12.8°C (55°F)	Accounts for transfer cool down & protects against (a) condensation (b) MPLM spec. lower limit
Ingress (120V Heaters)	N/A	15.6°C (60°F)	MPLM Activation complete w/MPLM ISS Shell heaters operational
Transfer to PLB (No Heaters)	773.1 mmHg 14.95 psia	(a) > 18.3°C (65°F) (b) > 12.8°C (55°F)	Accounts for transfer cool down & protects against (a) condensation (b) MPLM spec. lower limit
Return to Ground (28V Heaters)		(a) > 15.6°C (60°F) (b) > 10°C (50°F)	Accounts for transfer cool down & protects against (a) condensation (b) MPLM spec. lower limit
De-orbiting Landing	$P_{\text{ground}} - Dp_{\text{NPRV}}$	(a) > 15.6°C (60°F) (b) > 10°C (50°F)	To avoid atmosphere entering and contaminating MPLM



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# Mission Setpoint Analysis

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- Mission setpoints are loaded during KSC ground processing
- PTM setpoint optimized to maintain MPLM cabin air environment within pressure range to avoid:
  - ⌘ PPRA actuation (on-orbit)
  - ⌘ NPRV actuation (re-entry)
  - ⌘ Condensation
- MPLM heater usage remain within allocated STS-121 Shuttle power budget
- Relief Valve analysis constraints:
  - ⌘ 95% KSC landing site max pressure variations
  - ⌘ NPRV cracking pressure limit
  - ⌘ PPRV cracking pressure limit
- Final heater control parameters: SP= 25.6 C; Error span= +/- 0.2 C

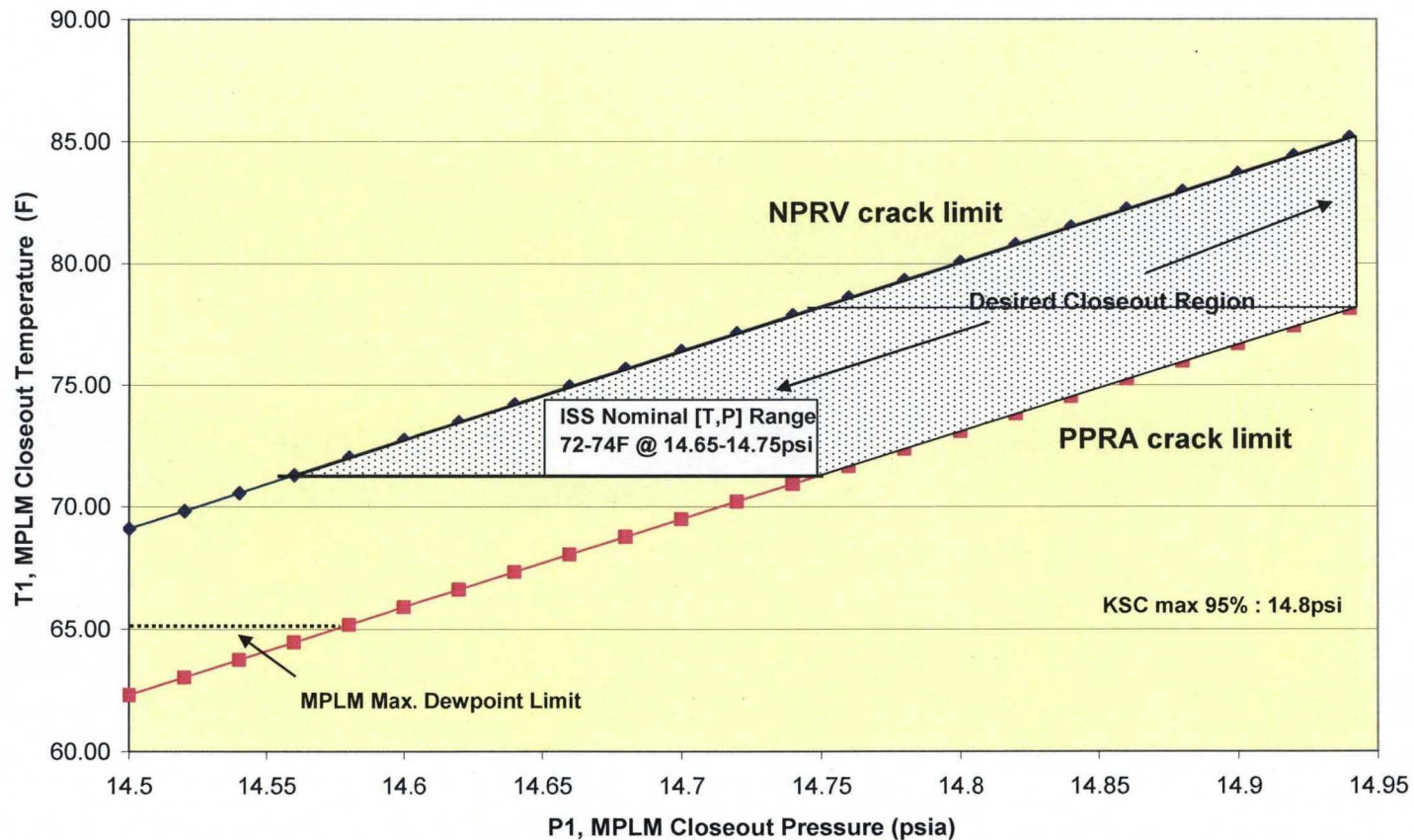


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# MPLM Pressure Relief Valve Chart

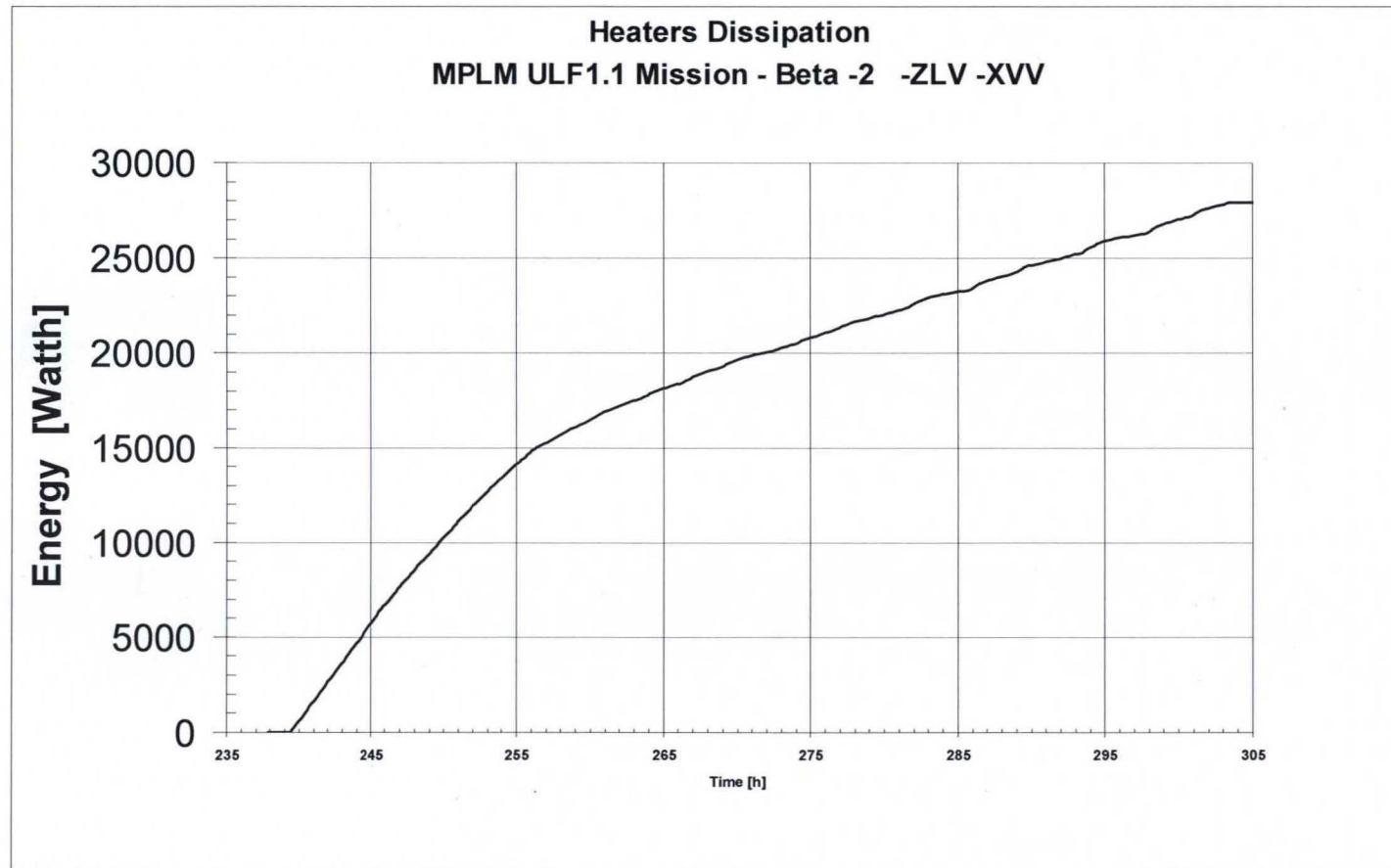
STS-121 MPLM/ ISS Closeout Conditions  
78F Setpoint, +/- 0.4 F Control Band



MPLM/ISS Closeout Conditions

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# ALTEC Thermal Verification Results



MPLM Pre-mission Thermal Verification Analysis

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# MPLM Cabin Air Pressures

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<b>Flight Day</b>	<b>APCU Act (GMT)</b>	<b>Cabin Temp °C &gt; 15.6 °C</b>	<b>Cabin Press kPa (psi) &lt; 103 kPa</b>	<b>Notes</b>
<b>FD11</b>	<b>195/20:35</b>	<b>19.41</b>	<b>100.0 (14 .51)</b>	<b>Environment Check (CFA Running)</b>
<b>FD11</b>	<b>196/11:53</b>	<b>24.88</b>	<b>102.0 (14.80)</b>	<b>Pressure Check (w/o CFA)</b>
<b>FD12</b>	<b>197/09:40</b>	<b>26.61</b>	<b>102.5 (14.87)</b>	<b>Pressure Check (w/o CFA)</b>



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# **Flight Performance**



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# Shell Heater Summary

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- Heater on-time: 60.83 hr
- DRM successfully captured all 20 PTM data channels
- Data acquisition rate: 1/min; 3647 total samples
- Heater Duty Cycle: 0.387 (on/off cycle counts)
- Heater Power consumption: 23.35 kWh

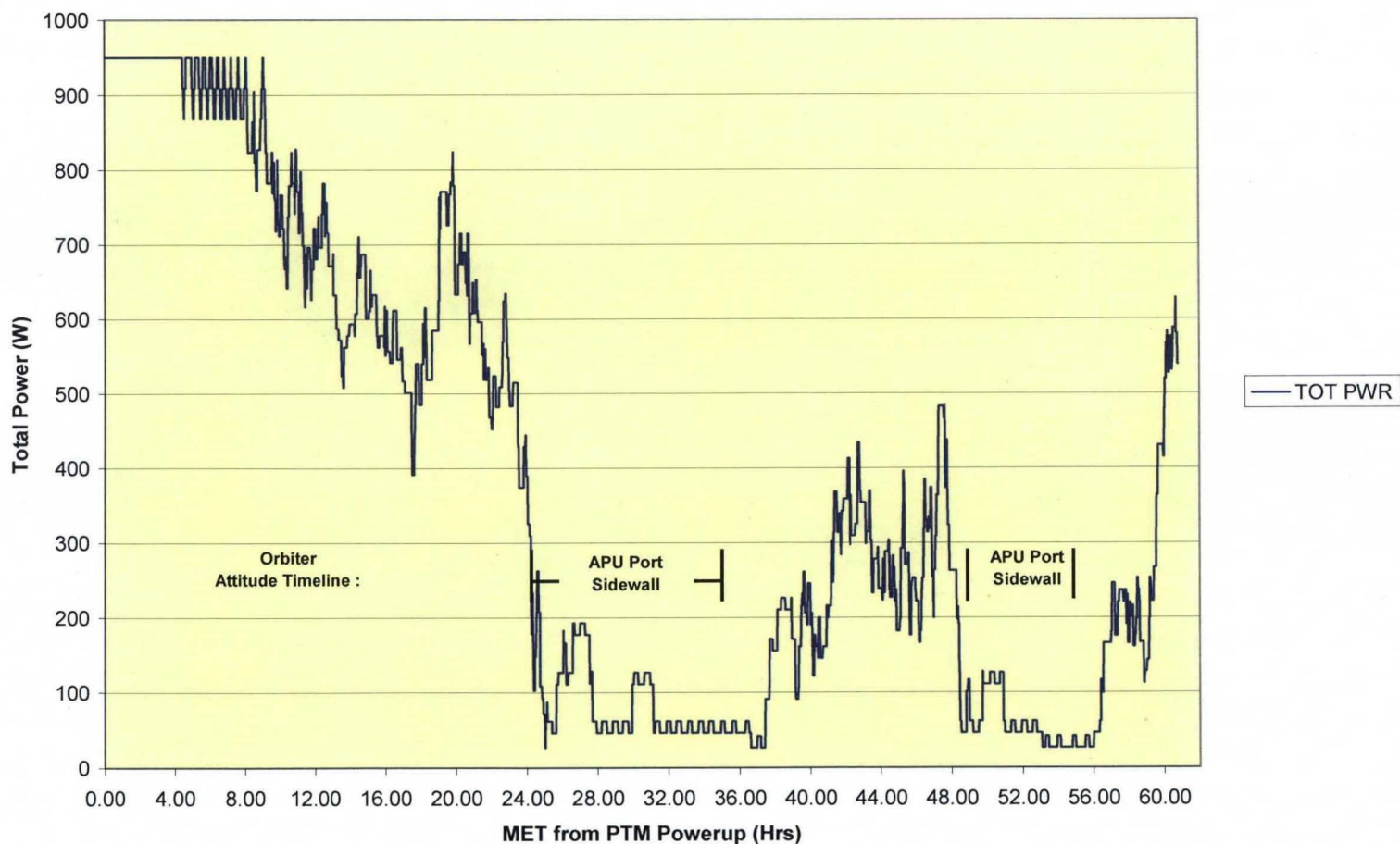


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# Shell Heater Power Profile

STS-121 Heater Power Profile

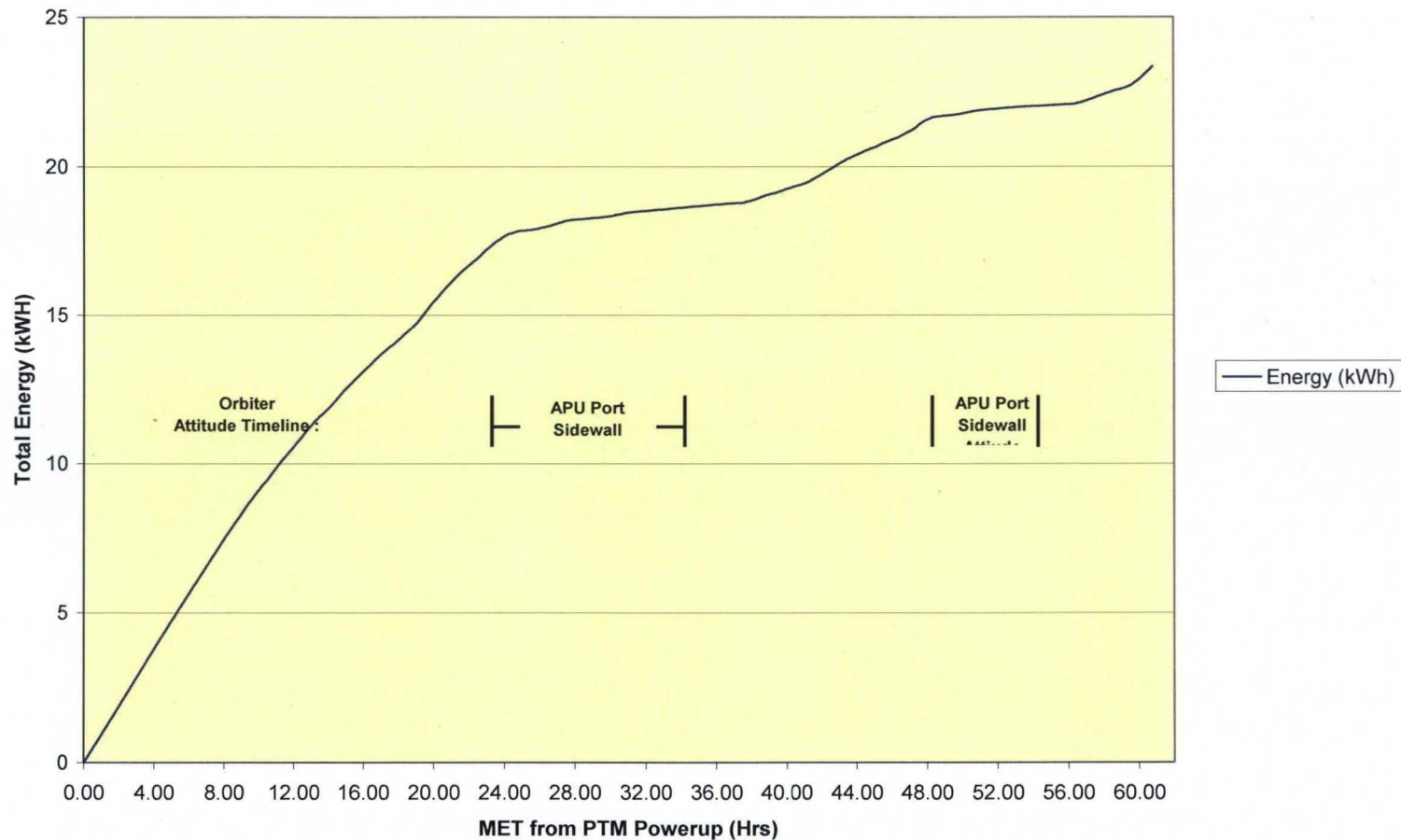


Heater Duty Cycle = 38%

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# STS-121 Shell Heater Power

STS-121 Energy Profile

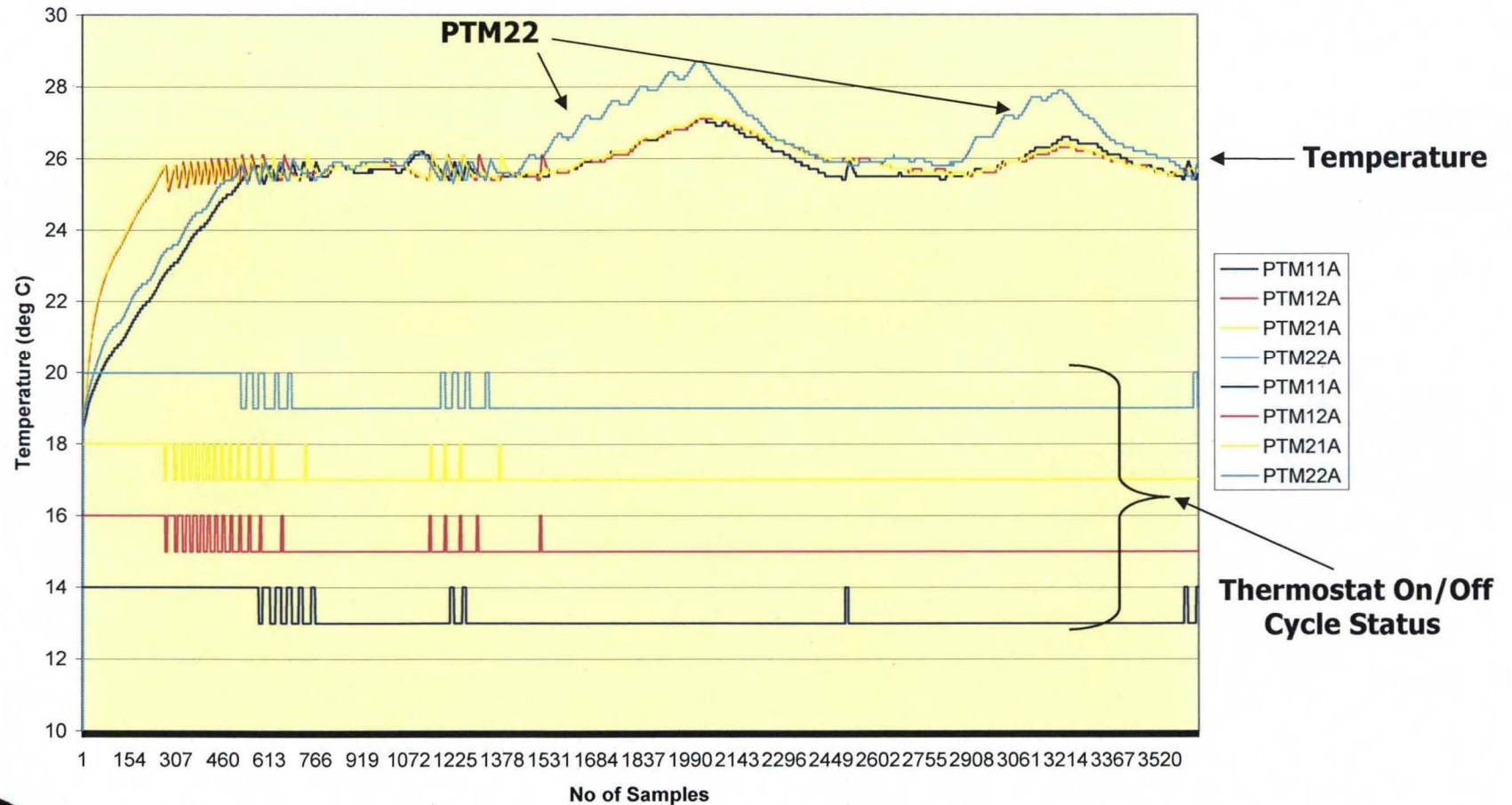


23 kWh (actual) vs 30kWh (planned)

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# Forward Endcone PTMs

FCON PTMs

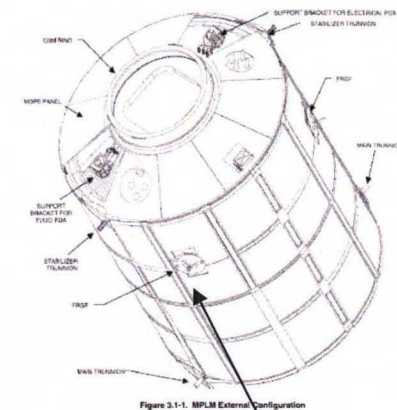
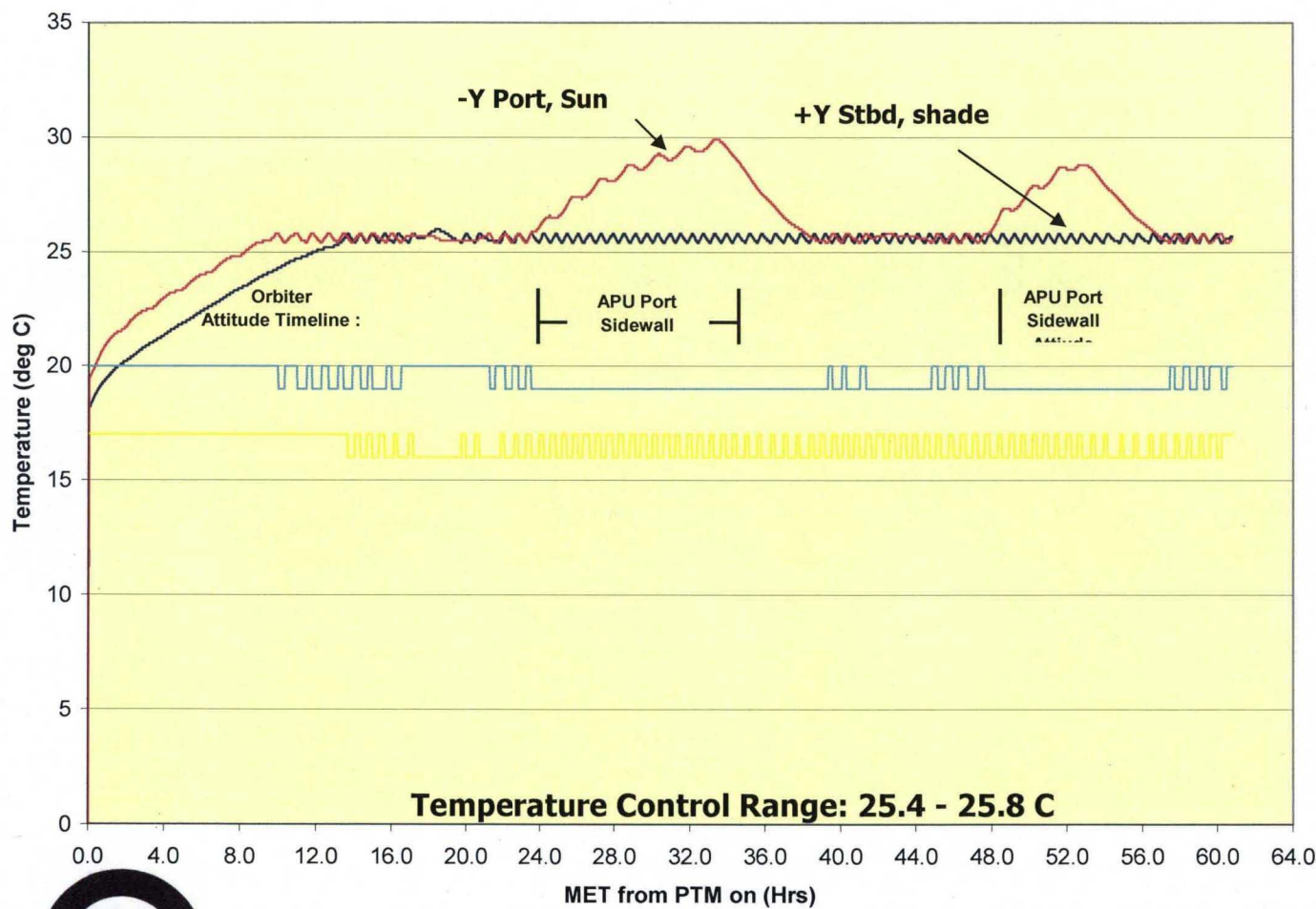


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# Grapple Fixture PTMs

Grapple Fixture (+Y/-Y) PTMs



GRAP(+Y)

GRAP(-Y)

GRAP(+Y)

GRAP(-Y)

+Y Stbd

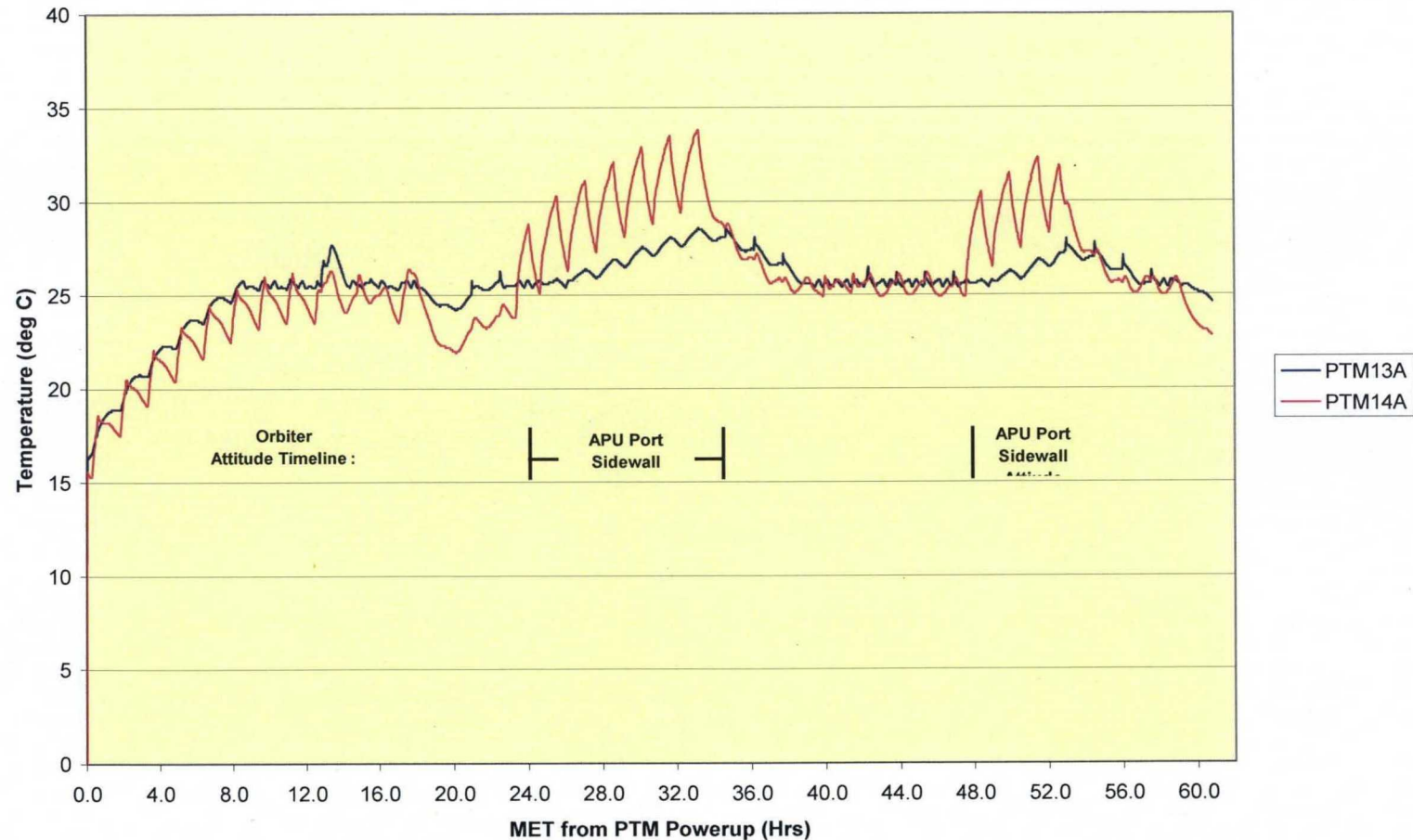


Illustration of Shuttle flight attitude heating influences

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# Common Berthing Mechanism PTMs

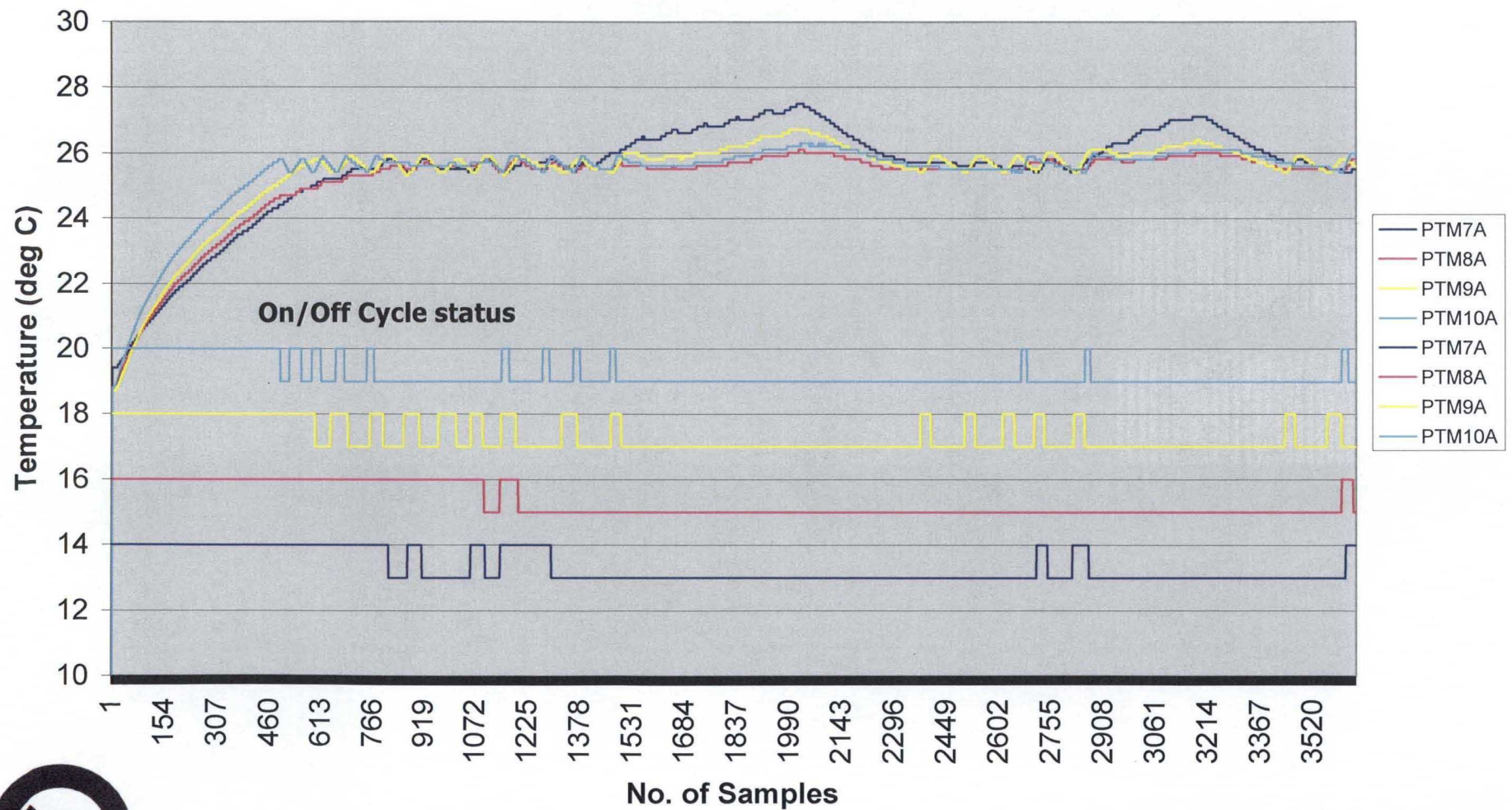
CBM PTMs



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# Aft Endcone PTMs

ACON PTMs

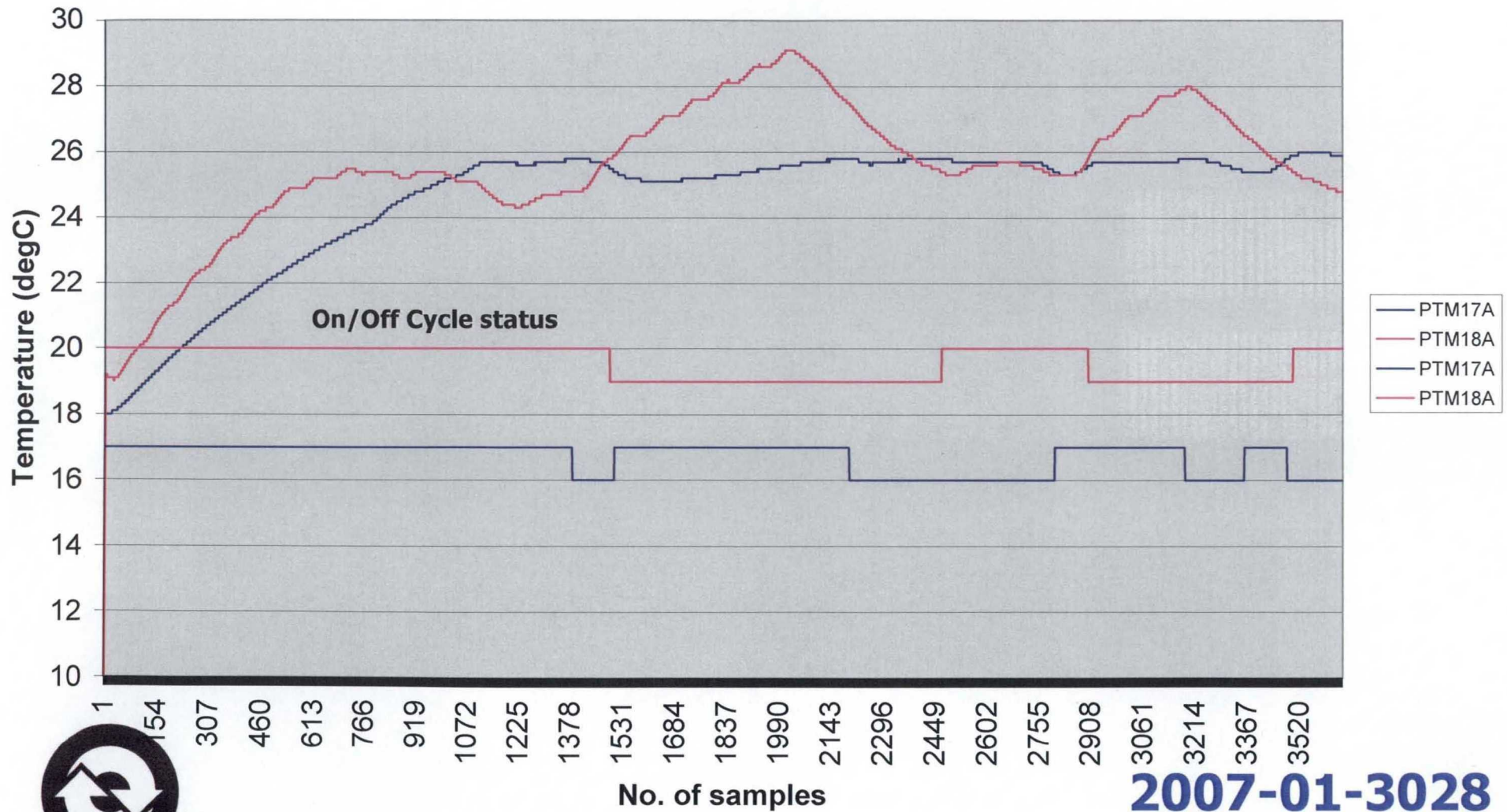


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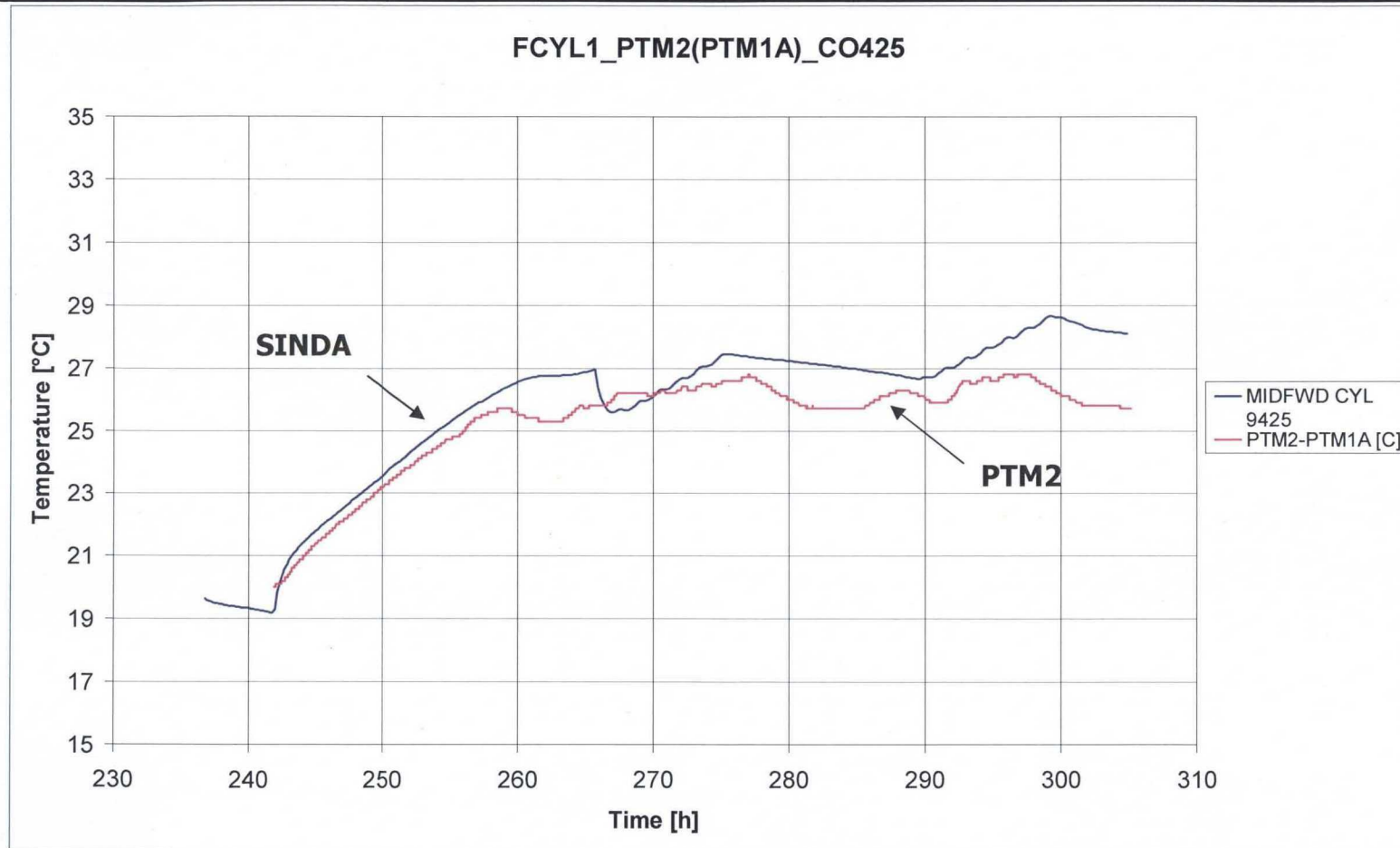


# Stabilizer & Main Fitting PTMs

Stabilizer & Main Fitting PTMs



# ALTEC Thermal Model Results



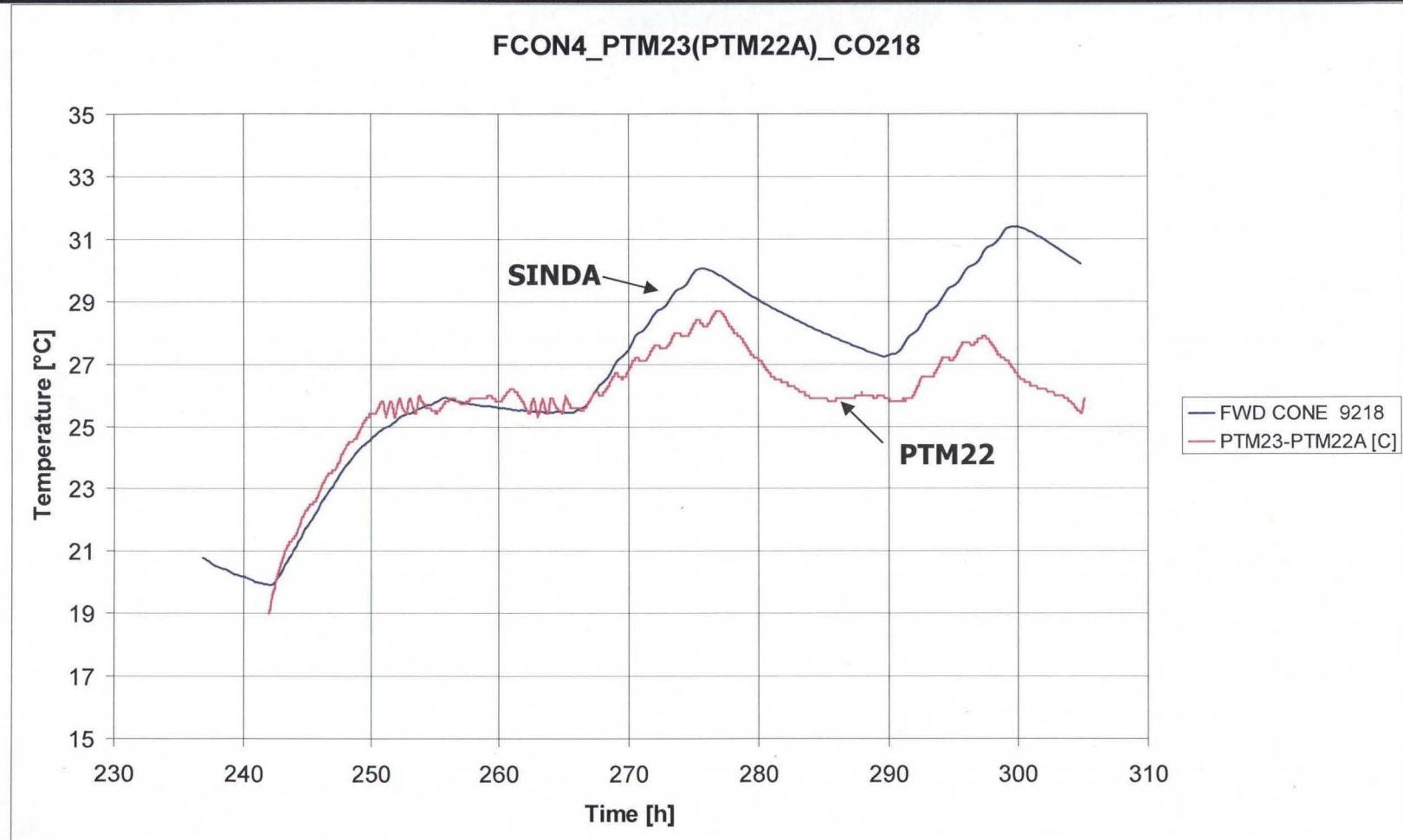
PTM2 vs SINDA model

Forward Cylinder

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# ALTEC Thermal Model Results



PTM22 vs SINDA model

Forward Endcone

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# Conclusions

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- Programmable Thermostats performed as designed
- Data acquisition functioned properly
- MPLM shell temperatures controlled within desired control range.
- PTM temperatures will be used to refine ALTEC SINDA thermal model for future missions



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